

**FOR REFERENCE**

**NOT TO BE TAKEN FROM THIS ROOM**

---

# **Viscous Computation of a Space Shuttle Flow Field**

---

Denny S. Chaussee, Yehia M. Rizk and  
Pieter G. Buning

---

June 1984

**LIBRARY COPY**

· 3 24 1984

LANGLEY RESEARCH CENTER  
LIBRARY, NASA  
HAMPTON, VIRGINIA



National Aeronautics and  
Space Administration



NF00832

---

# Viscous Computation of a Space Shuttle Flow Field

---

Denny S Chaussee

Pieter G Buning, Ames Research Center, Moffett Field, California

Yehia M Rizk, Informatics General Corporation, 1121 San Antonio Road,  
Palo Alto, California



National Aeronautics and  
Space Administration

**Ames Research Center**  
Moffett Field, California 94035

*N84-30225-7*

## VISCOUS COMPUTATION OF A SPACE SHUTTLE FLOW FIELD

D. S. Chaussee, Y. M. Rizk, and P. G. Buning  
NASA Ames Research Center  
Moffett Field, CA 94035 USA

### I. INTRODUCTION

Recent research efforts [1-3] have confirmed the ability of the "parabolized" Navier-Stokes (PNS) codes to predict accurately and rapidly the aerothermodynamics of the actual Space Shuttle Orbiter up to an axial station that is 50% of the overall length. This corresponds to a location where the strake ends and the 45° swept wing begins. In the past, the geometry of the Orbiter usually has been modified [4-7] such that a solution over the complete body was possible. These modifications take the form of changing the sweep angle of the wing, removing the canopy, and altering the lee of the body so that the cross section is composed of two elliptical shapes. In one instance [8], an inviscid solution was obtained for the complete Orbiter. In order to perform this calculation, a "fix" had to be used in the vicinity of the bow-shock/wing-shock interaction region. Physically, what occurs is a region of embedded subsonic flow owing to the bow-shock/wing-shock interaction which causes the resulting coalescing shock wave to be more normal to the flow for a short streamwise distance. Since the above inviscid procedure was a marching code, it failed when the Mach number in the marching direction became subsonic.

A viscous numerical procedure is described, to compute the flow over the Shuttle. Results are presented that demonstrate the capability of the method. Obtainment of these results requires the use of two computer codes. A PNS code [9,10] is used to obtain the solution up to the bow-shock/wing-shock interaction region, and an unsteady continuation code is used for the region after the shock interaction. The unsteady Navier-Stokes code [11] is also used to obtain the blunt-body starting solution. Only results from the marching code will be presented. For the flow conditions calculated, that is,  $M_\infty = 7.9$ ,  $\alpha = 25^\circ$ ,  $T_{\text{wall}} = 540^\circ\text{R}$ ,  $Re_L = 60,728/\text{in.}$ , laminar or turbulent, the PNS code has been marched up to an  $X/L = 0.7$  which is where the bow-shock/wing-shock interaction region occurs. In this work,  $L$  refers to the length of the vehicle.

### II. COMPUTATIONAL TECHNIQUE

The PNS equations are obtained from the complete Navier-Stokes equations by neglecting the unsteady terms and the streamwise viscous derivative terms. The complete details of all the terms and derivations can be found in Ref. 12.

In the present formulation,  $\xi$  (the marching direction in computational space) is a function of  $x$  only (axis-normal marching planes). The governing equations are hyperbolic-parabolic in this  $\xi$ -direction if the inviscid part of the flow field is supersonic, if there is no streamwise (axial) separation, and if the pressure gradient in the viscous region near the wall is treated correctly. However, the system of equations still allows for the separation in the crossflow plane ( $\eta$ - $\zeta$ ).

The present PNS code uses the Beam-Warming implicit algorithm to update the interior of the region and characteristic, implicit, spatially second-order-accurate boundary conditions at the outermost shock wave. An elliptic grid generator of the type developed by Steger and Sorenson [13] and further specialized to wing bodies by Rai et al. [10] is used to generate the grid for the calculations.

If the conditions in a particular region are such that the marching procedure is invalidated, the unsteady Navier-Stokes (UNS) code is used for these regions. In calculating the flow over the Space Shuttle, one such region occurs in the vicinity of the bow-shock/wing-shock interaction (a pocket of subsonic flow is encountered).

The complete details of the UNS code can be found in Ref. 11. The UNS code is extremely versatile and relatively easy to use. It uses either a Beam-Warming implicit algorithm or a hybrid scheme due to Rizk and Chaussee [11]. The outer shock wave is either fitted or captured. Usually the initial guess is furnished by the PNS code, which is modified in some manner to march through regions where it would not march before. This procedure is acceptable, since the unsteady code takes this reasonable guess and iterates in time until a steady-state solution is obtained.

The domain of this unsteady calculation encompasses the subsonic flow. The outflow boundary consists entirely of supersonic axial flow in the inviscid part of the flow field. This permits the PNS code, which is more efficient, to continue marching from this point.

### III. RESULTS

Numerical results have been obtained for the following wind-tunnel conditions:  $M_\infty = 7.9$ ,  $\alpha = 25^\circ$ ,  $T_{\text{wall}} = 540^\circ\text{R}$ ,  $Re_L = 60,728/\text{in.}$  turbulent flow. For this calculation, the Shuttle surface coordinates were obtained from Rockwell-International Corporation. The current geometry consists of the complete Shuttle; the canopy, OMS pods, and the vertical stabilizer are included.

The three-dimensional blunt-body code originally developed by Kutler et al. [14] was used to obtain the blunt-nose solution which creates the necessary starting planes for the PNS code at  $X/L = 0.0522$ . This solution was then marched downstream using the elliptic grid generator to construct the grid between the body and the fitted outermost shock wave. The grid consisted of either 61 or 121 points in the meridional direction and 45 geometrically stretched radial points. An example of the grid at an  $X/L = 0.66$  is shown in Fig. 1. The outermost grid line is the bow wave, which is fitted using an implicit technique.

The pressure contours in the region of the canopy are presented in Figs. 2 and 3. In Fig. 2, the contours on the lee pitch plane of symmetry between  $X/L = 0.067$  and  $X/L = 0.4$  are shown. In the canopy region, the coalescence of contours details the canopy shock wave followed by an expansion wave on the lee of the Shuttle. The contours for a cross section at an  $X/L = 0.2$  are presented in Fig. 3. The canopy shock is once again viewed at the point on the lee where the pressure contours

coalesce. The expansions which are visible on the windward are due to discontinuities in geometry.

The Mach number contours at an  $X/L = 0.66$  are presented in Fig. 4. The main features are the wing shock and the crossflow shocks on the wing and upper body, respectively. These are denoted by the coalescence of the Mach contours.

In Fig. 5, the crossflow velocity vectors are presented at an  $X/L = 0.66$ . Two interesting features seen in this figure are the recirculation region in the wing-body juncture and the lee vortex.

The density contours in the vicinity of the wing tip at an  $X/L = 0.667$  are shown in Fig. 6. The wing shock and the bow shock have interacted as characterized by the bulge in the outer boundary. This is due to the wing shock becoming the outermost surface, with the bow shock being captured. The bow shock appears as the coalescence of the density contours near the outer surface.

By numerically simulating oil flow on the surface of the vehicle, as in Fig. 7, many interesting features are observed. The lines of separation on both the strake-wing and the lee of the body are evident by the coalescence of the numerical oil flow. The reattachment line is visible on the Shuttle as a series of oil-flow lines diverging toward the separation lines.

The computer-generated particle paths of Fig. 8 exhibit the same trends in the flow field that are visible on the Shuttle surface via the oil flow. Specific features are the vortices on the lee which are due to the strake-wing. At this angle of attack, the vortices that are generated on the wing impact on the OMS pod.

#### IV. SUMMARY

A procedure has been presented for calculating the flow over vehicles that have embedded regions of subsonic flow in the inviscid part of the flow field. A PNS marching code is used to obtain the solution up to the bow-shock/wing-shock interaction region. In this interaction region, the UNS code can be employed since the region has a pocket of subsonic flow. Currently, only the results for the marching code up to an  $X/L = 0.667$  are included. In the future, the results for the bow-shock/wing-shock region will be available.

#### V. REFERENCES

1. Venkatapathy, E., Rakich, J. V., and Tannehill, J. C., "Numerical Solution of Supersonic Viscous Flow over Blunt Delta Wings," AIAA Paper 82-0028, 1982.
2. Prabhu, D. K. and Tannehill, J. C., "Numerical Solution of Space Shuttle Orbiter Flow Field Including Real Gas Effects," AIAA Paper 84-1747, 1984.
3. Balakrishnan, A., "Computation of Viscous Real Gas Flow Field for the Space Shuttle Orbiter," AIAA Paper 84-1748, 1984.
4. Li, C. P., "Application of an Implicit Technique to the Shock-Layer Flow Around General Bodies," AIAA Journal, Vol. 20, 1982, p. 175.
5. Szema, K. Y., Griffith, B. J., Maus, J. R., and Best, J. T., "Laminar Viscous Flow Field Prediction of Shuttle-like Vehicle Aerodynamics," AIAA Paper 83-0211, 1983.
6. Weilmuenster, K. J., "High Angle of Attack Inviscid Flow Calculations Over a Shuttle-like Vehicle with Comparisons to Flight Data," AIAA Paper 83-1798, 1983.

7. Weilmuenster, K. J. and Hamilton, H. H., "Calculations of Inviscid Flow Over Shuttle-like Vehicles at High Angles of Attack and Comparisons with Experimental Data," NASA TP-2103, 1983.
8. Chaussee, D. S., Kutler, P., and Holtz, T., "Inviscid Supersonic/Hypersonic Body Flow Field and Aerodynamics from Shock-Capturing Technique Calculations," Journal of Spacecraft & Rockets, Vol. 13, 1976, pp. 325-331.
9. Rai, M. M. and Chaussee, D. S., "New Implicit Boundry Procedures: Theory and Applications," AIAA Paper 83-0123, 1983.
10. Rai, M. M., Chaussee, D. S., and Rizk, Y. M., "Calculation of Viscous Supersonic Flows over Finned Bodies," AIAA Paper 83-1667, 1983.
11. Rizk, Y. M. and Chaussee, D. S., "Three-Dimensional Viscous-Flow Computations Using a Directionally Hybrid Implicit-Explicit Procedure," AIAA Paper 83-1785, 1983.
12. Schiff, L. B. and Steger, J. L., "Numerical Simulation of Steady Supersonic Viscous Flow," AIAA Paper 79-0130, 1979.
13. Steger, J. L. and Sorenson, R. L., "Automatic Mesh-Point Clustering Near a Boundary in Grid Generation with Elliptic Partial Differential Equations," Journal of Computational Physics, Vol. 33, 1979, pp. 405-410.
14. Kutler, P., Pedelty, J. A., and Pulliam, T. H., "Supersonic Flow Over Three-Dimensional Ablated Nosedtips using an Unsteady Implicit Numerical Procedure," AIAA Paper 80-0063, 1980.

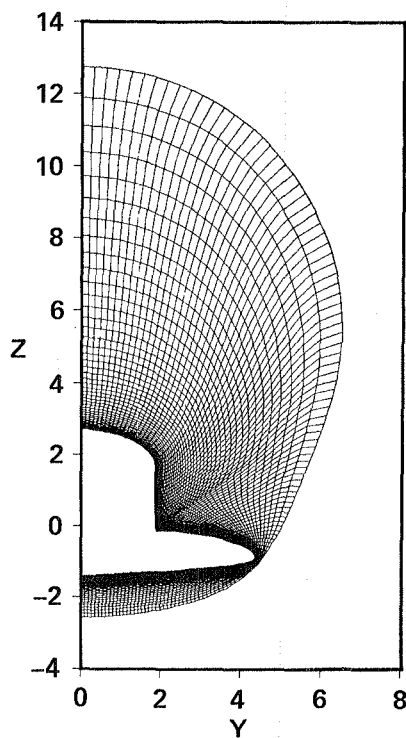


Fig. 1 Elliptic grid at  $X/L = 0.66$ .

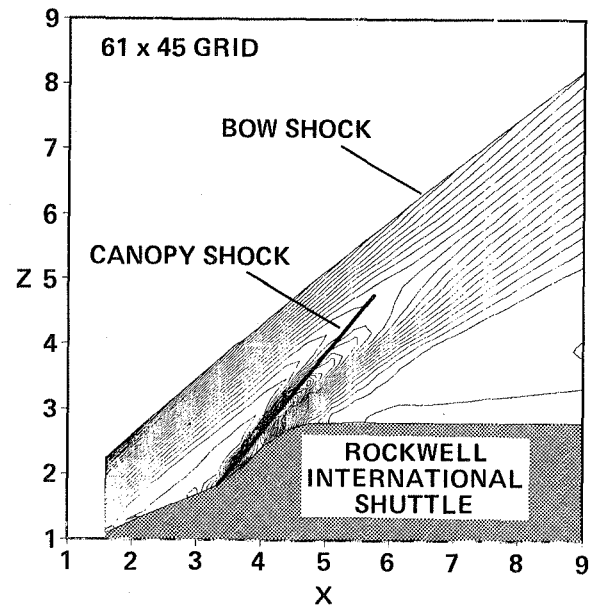


Fig. 2 Pressure contours in the lee pitch plane of symmetry.

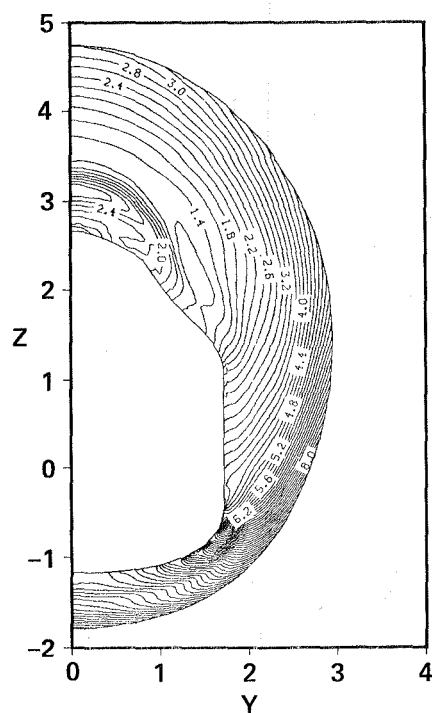


Fig. 3 Pressure contours at  $X/L = 0.2$ .

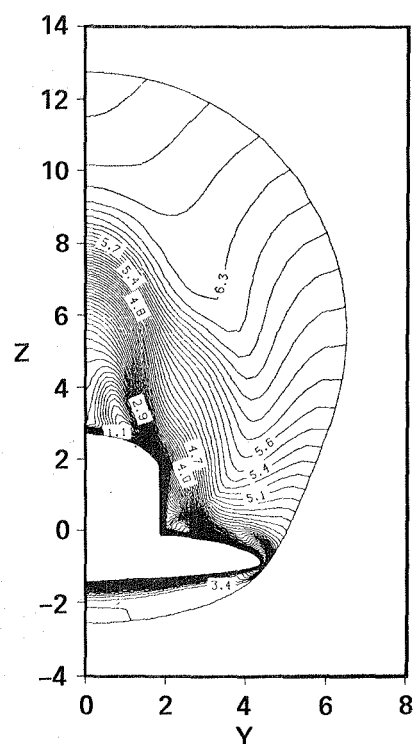


Fig. 4 Mach contours at  $X/L = 0.66..$

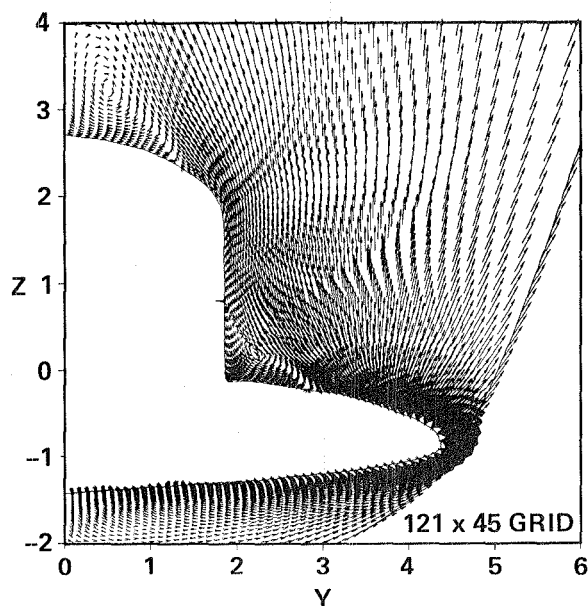


Fig. 5 Crossflow velocity vectors at  $X/L = 0.66$ .

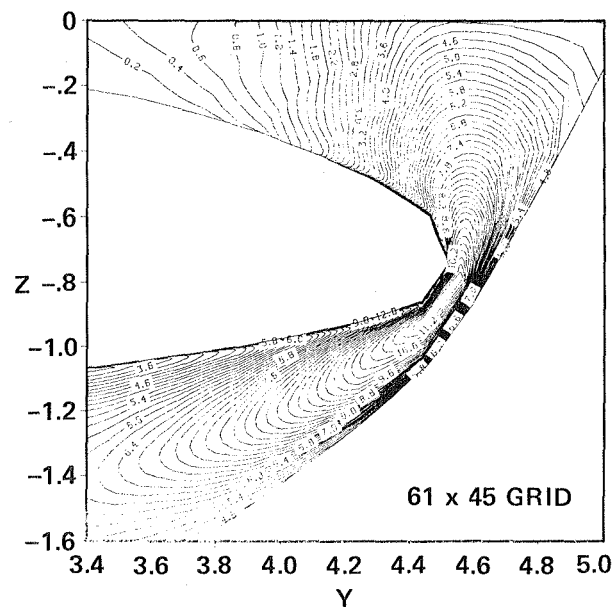


Fig. 6 Density contours near the wing tip  
at  $X/L = 0.667$ .

61 x 45 GRID

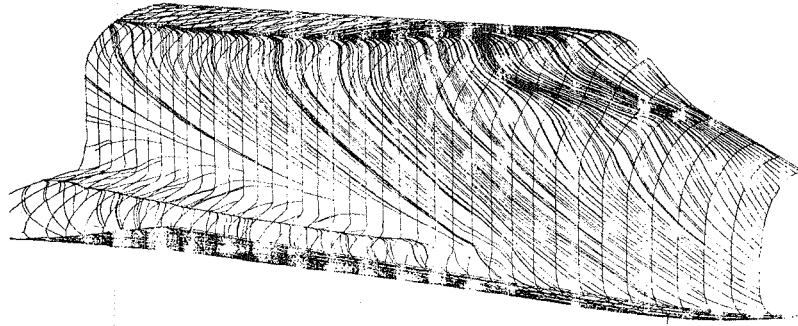


Fig. 7 Computational oil flow on the Shuttle surface up to  $X/L = 0.66$ .

61 x 45 GRID

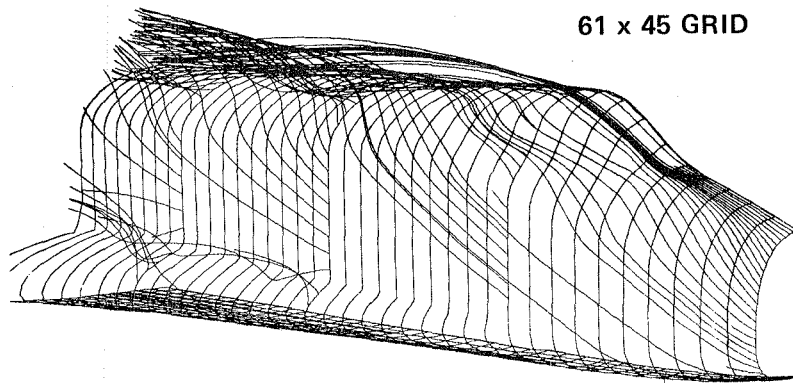


Fig. 8 Computational particle paths up to  $X/L = 0.66$ .



1 Report No NASA TM 85977	2 Government Accession No	3 Recipient's Catalog No	
4 Title and Subtitle  VISCOUS COMPUTATION OF A SPACE SHUTTLE FLOW FIELD		5 Report Date June 1984	
		6 Performing Organization Code A-9799	
Denny S. Chaussee, Yehia M. Rizk* and Pieter G. Buning		8 Performing Organization Report No	
		10 Work Unit No T-6458	
9 Performing Organization Name and Address  Ames Research Center Moffett Field, CA 94035		11 Contract or Grant No	
		13 Type of Report and Period Covered Technical Memorandum	
12 Sponsoring Agency Name and Address  National Aeronautics and Space Administration Washington DC, 20546		14 Sponsoring Agency Code 505-31-01	
15 Supplementary Notes *Informatics General Corporation, Palo Alto, CA Point of contact. Denny S. Chaussee, Ames Research Center, MS 292A-14 Moffett Field, CA 94035, (415) 965-6742 or FTS 448-6742			
16 Abstract  A procedure is presented, as well as some results, to calculate the flow over the winged Orbiter. This necessitates the use of two computer codes. A parabolized marching Navier-Stokes code is used to obtain the solution up to the bow shock-wing shock interaction region and for the region after the interaction. An unsteady Navier-Stokes code is to be used in the region of the shock interaction. Only results for the marching code are presented. For the flow conditions calculated, $M_\infty = 7.9$ , $\alpha = 25^\circ$ , $T_{wall} = 540^\circ R$ , $Re_L = 60728$ per inch, laminar or turbulent, the PNS code has been marched up to an $X/L = 0.7$ which is where the bow shock-wing shock interaction region occurs.			
17 Key Words (Suggested by Author(s)) Computational fluid dynamics Supersonic flow Shuttle Three-dimensional viscous flow		18 Distribution Statement  Unlimited  Subject category: 34	
19 Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages 8	22 Price* AO2

**End of Document**